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Contents:

"DEVELOPMENTS IN GEAR GUTTING AND FINISHING PROCESSES"

by F. J. EVEREST, M.Sc., A.M.I.Mech.E., A.M.I.E.E.

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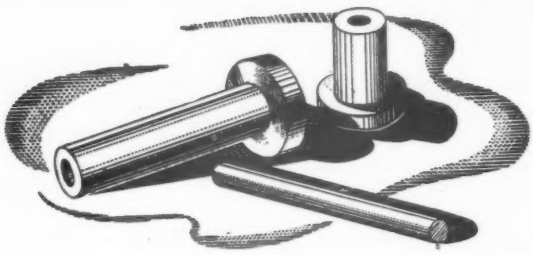

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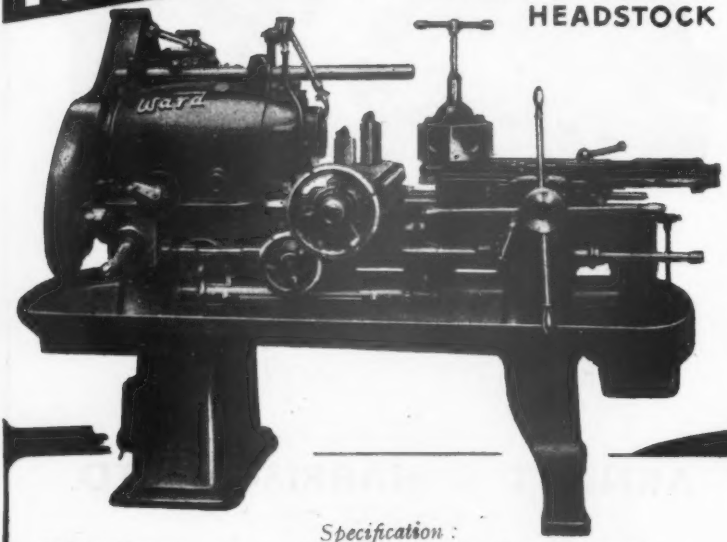

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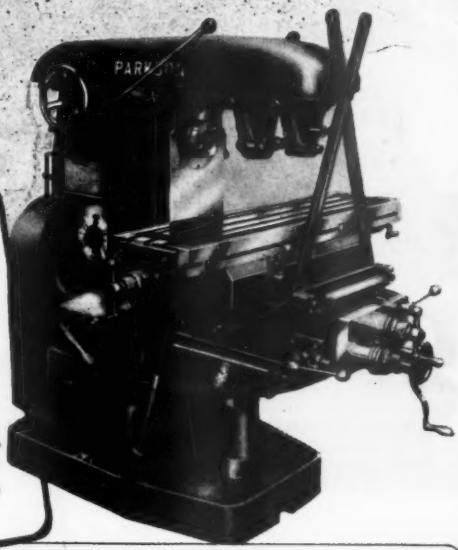

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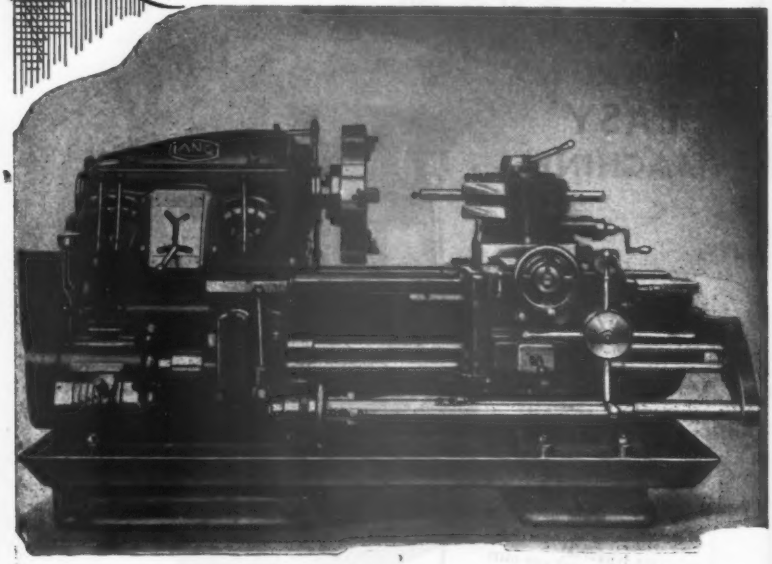

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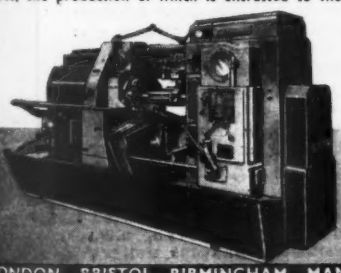

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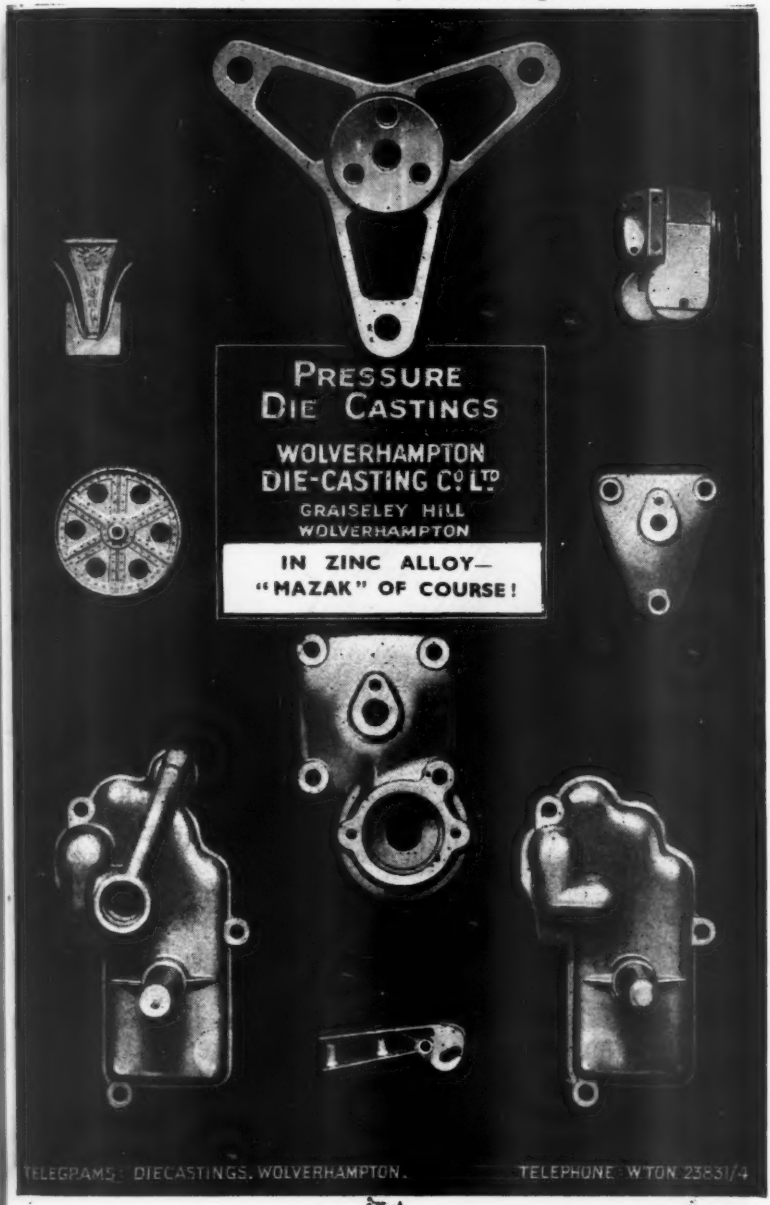
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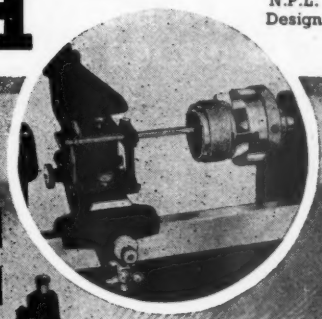

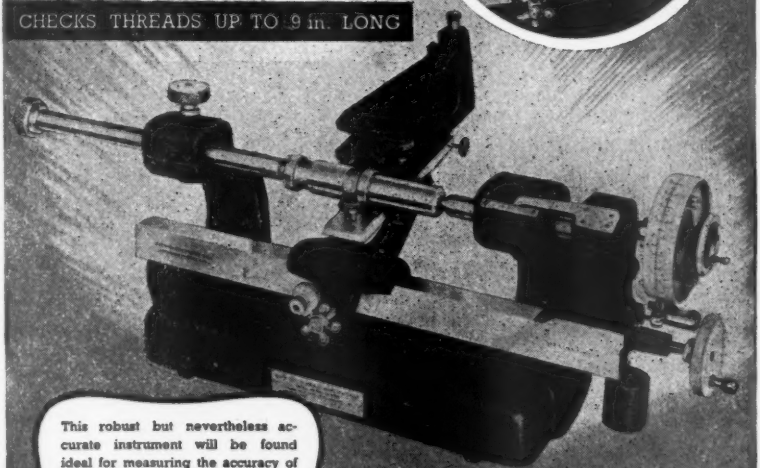

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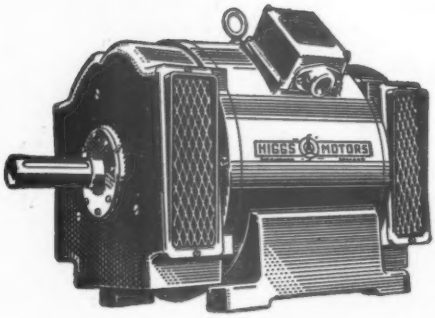

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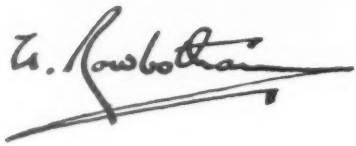

Norman Rowbotham, C.B.E., B.Sc., M.I.P.E., F.R.Ae.S. Born in Manchester in 1892, Mr. Rowbotham served his engineering apprenticeship with the Great Central Railway at their locomotive works at Gorton, Manchester. Obtaining a Whitworth Exhibition in 1914, and later graduating B.Sc. i n engineering at London University, he joined the Aeronautical Inspection Department early in 1915.

He was invited to join the Bristol Aeroplane Company in 1922, going to France to supervise the manufacture of Bristol aircraft engines at the works of their Licensee, the Gnome & Le Rhone Company, Paris. In 1927 he was appointed Chief Engineer of the French Company and remained in that post until 1931, when he returned to England by arrangement with the Bristol Company.

From the position of Works Manager of the Bristol Aeroplane Company's engine factories up to 1943, Mr. Rowbotham was then appointed Chief Engineer of the Engine Division, and was invited to join the Board of the Company. He is now Divisional Managing Director of the Bristol Company's Piston Engine and Turbine organisation.

Mr. Rowbotham was President of the Western Section of the Institution of Production Engineers during the period 1934-36.

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INSTITUTION NOTES

July, 1946

July Meetings

4th Wolverhampton Graduate Section. Visit to the Birmingham Gazette Buildings, Birmingham, at 2-30 p.m.

11th Shrewsbury Sub-Section. A lecture will be given by J. H. Paterson, Esq., D.Sc., F.R.I.C., on "The Principles Involved in Fabrication to replace Castings," at the Technical College, Shrewsbury, at 7.30 p.m.

13th Leicester Section. Visit to Messrs. Fischer Bearing Co., Ltd., Wolverhampton, starting at 7-45 a.m.

July Committee Meetings

16th Education Committee, at 10-30 a.m., at the Queen's Hotel, Birmingham.

16th Membership Committee, at 12-30 p.m., at the Queen's Hotel, Birmingham.

19th Finance and General Purpose Committee, at 2-30 p.m., in the TEMPORARY Committee Room, 36, Portman Square, London, W.1.

— Research Committee, at 11-45 a.m., at Loughborough College, Loughborough, Leics.

Technical and Publications Committee meets every Wednesday at 5-30 p.m., in the TEMPORARY Committee Room, 36, Portman Square, London, W.1.

Until further notice, meetings of the Finance and General Purposes Committee, the Technical and Publications Committee, and the London Section Committee will be held in the TEMPORARY Committee Room at 36, Portman Square, London, W.1. All correspondence is still to be addressed to No. 10, Seymour Street, London, W.1.

Birthday Honours

Our sincere congratulations are extended to Dr. H. Schofield, M.I.P.E., and Mr. T. Fraser, M.I.P.E., on whom His Majesty the King has been pleased to confer the C.B.E.

Personal

Mr. Stewart Owen, Grad.I.P.E., has been appointed Acting Area Manager for the David Brown & Sons (Huddersfield) Ltd. group of companies in Scotland.

Mr. Owen was awarded the M.B.E. (Military Division) in the New Year's Honours List.

Shrewsbury Sub-Section

A lecture entitled "Developments in Gear Cutting and Finishing Processes," which appears in this issue of the Journal, was given by Mr. F. J. Everest, M.Sc., A.M.I.Mech.E., A.M.I.E.E., on Thursday, 16th May, 1946, at the Shrewsbury Technical College. The lecture was greatly appreciated, and letters of thanks have been sent to Mr. Everest and to Mr. A. Moore, Principal of Shrewsbury Technical College.

Obituary

We deeply regret to announce the deaths of Mr. Cyril H. Rathbone, Grad.I.P.E., and Mr. J. S. Reed, M.I.P.E.

Books Received

Planning Local Prosperity, by K. G. Fenelon, M.A., Ph.D. Published by Art and Educational Publishers, Ltd., London and Glasgow. Price 1/6 net.

The Economics of Automatic Machine Operation, by E. E. Fluskey. Published by The Machinery Publishing Co., Ltd., Brighton. Price 7/6 net.

Issue of Journal to New Members

Owing to the fact that output has to be adjusted to meet requirements, and in order to avoid carrying heavy stocks, it has been decided that the Journal will only be issued to new Members from the date they join the Institution.

Important

In order that the Journal may be despatched on time, it is essential that copy should reach the Head Office of the Institution not later than 40 days prior to the date of issue, which is the first of each month.

DEVELOPMENTS IN GEAR CUTTING AND FINISHING PROCESSES

By F. J. EVEREST, M.Sc., A.M.I.Mech.E., A.M.I.E.E.

Presented to Leicester Section, 13th December, 1945, and to Shrewsbury Sub-Section, 16th May, 1946.

The gear cutting industry is essentially a modern development and although in the making of clocks, watches and scientific instruments machine cut gears have long been used, their application to general engineering on any considerable scale extends only over the last 50 years.

It is a remarkable fact that at the beginning of the century the theory and design of gears was considerably in advance of production technique, but in recent years this state of affairs has undoubtedly been rectified.

Among the best known early publications is Brown and Sharpe's treatise on gears, dated 1902, and a particularly interesting book by George B. Grant, of Philadelphia, published in 1899, gives the elementary principles of almost every conceivable type of gear. It is interesting to note that the hypoid, which is popularly regarded as one of the most recent developments and has, in fact, only been generally applied during the last 15 years, is clearly described and given the name of " hypoid " in Grant's book.

It had been regular practice before the commencement of the present century, to use gear cutting machines to make wood patterns and, from this, there was a logical development to the cutting of metal patterns and, later, the cutting of actual gears.

In the early stages, rotary milling processes were the most common, employing single, or, in some cases, gang cutters, operating on two or three teeth at a time and there was a tendency to use machines of a universal character. For example, universal milling machines were regularly used to cut either spur or spiral gears or racks, and the earlier automatic gear cutting machines were generally developments of the milling process.

At a later stage, various generating processes were developed and this led to a general adoption of involute teeth in preference to cycloidal teeth. The involute shape possesses many advantages from the production point of view, without any measurable disadvantage in other respects. It can readily be generated from first principles, the fundamental requirement being to traverse a cutting point in a line tangential to the base circle of the involute and at the same

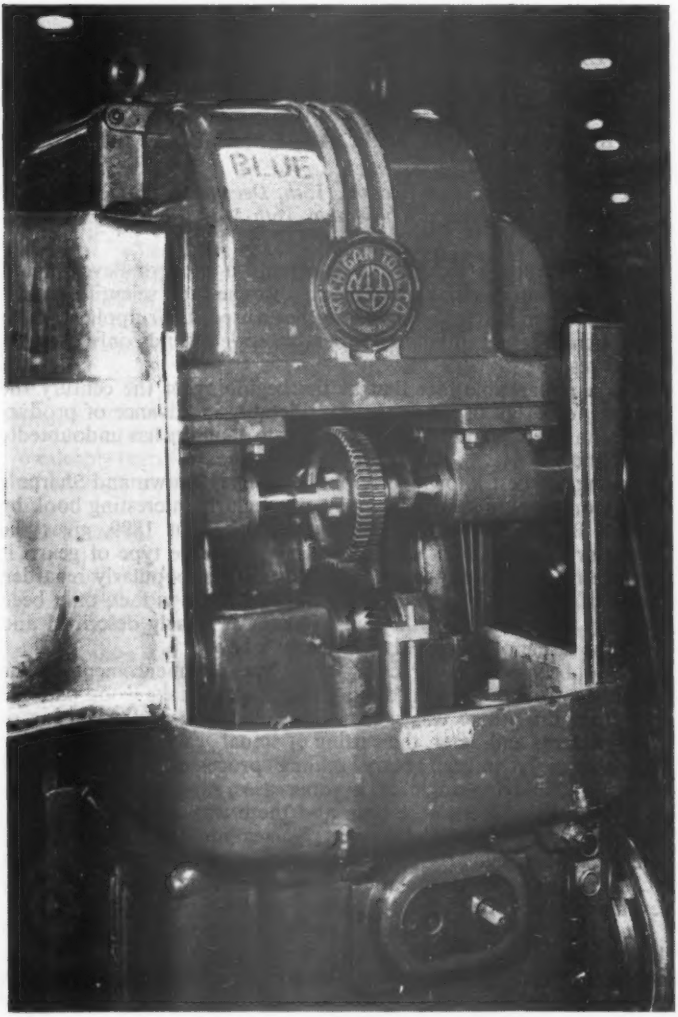

FIG. 1. Shaving machine for small spur and helical gears.

linear velocity or, alternatively, to traverse a straight sided rack tooth, with suitable cutting edges, on a line tangential to the pitch circle of the gear and at the same linear velocity as the pitch circle. A transverse cutting motion must, of course, be superimposed in actual gear cutting.

Just as gear cutting, in itself, has become a specialised branch of engineering, so there has been a tendency to develop specialised machines for cutting each type of gear.

Spur and Helical Gears.

Outstanding figures in this country in the early development of gear cutting were John Sunderland of Keighley and his son, Sam

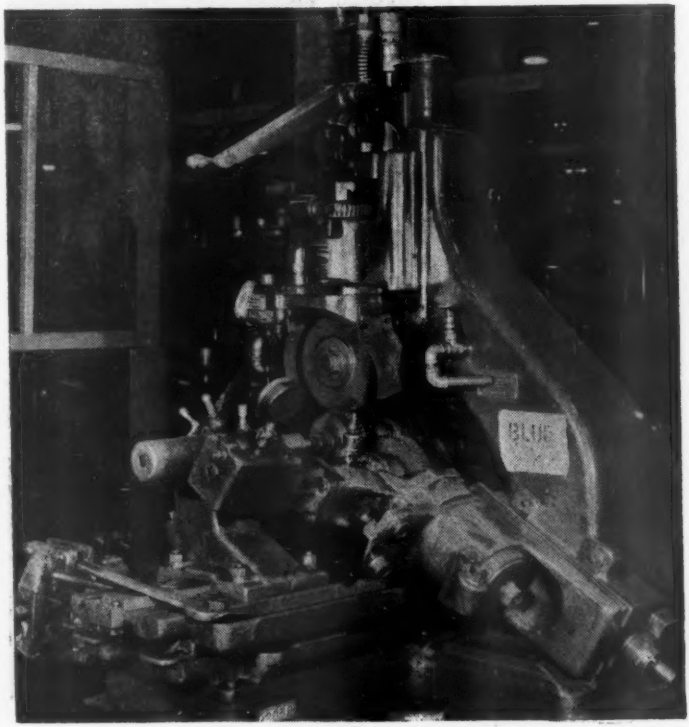

FIG. 2. Crossed axis lapping machine.

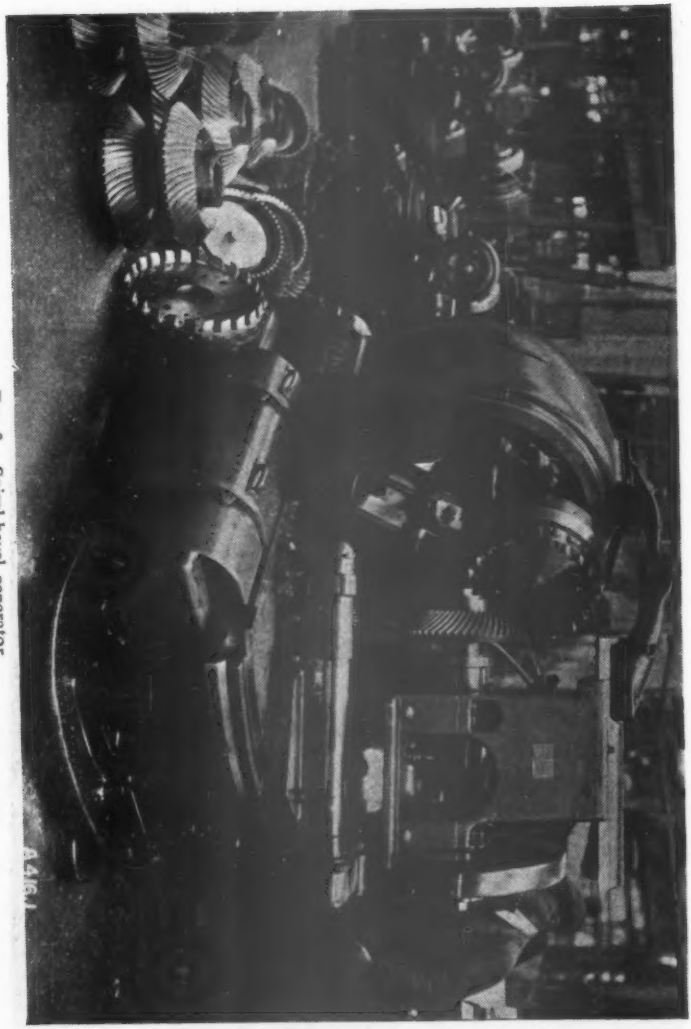

FIG. 3. Spiral bevel generator.

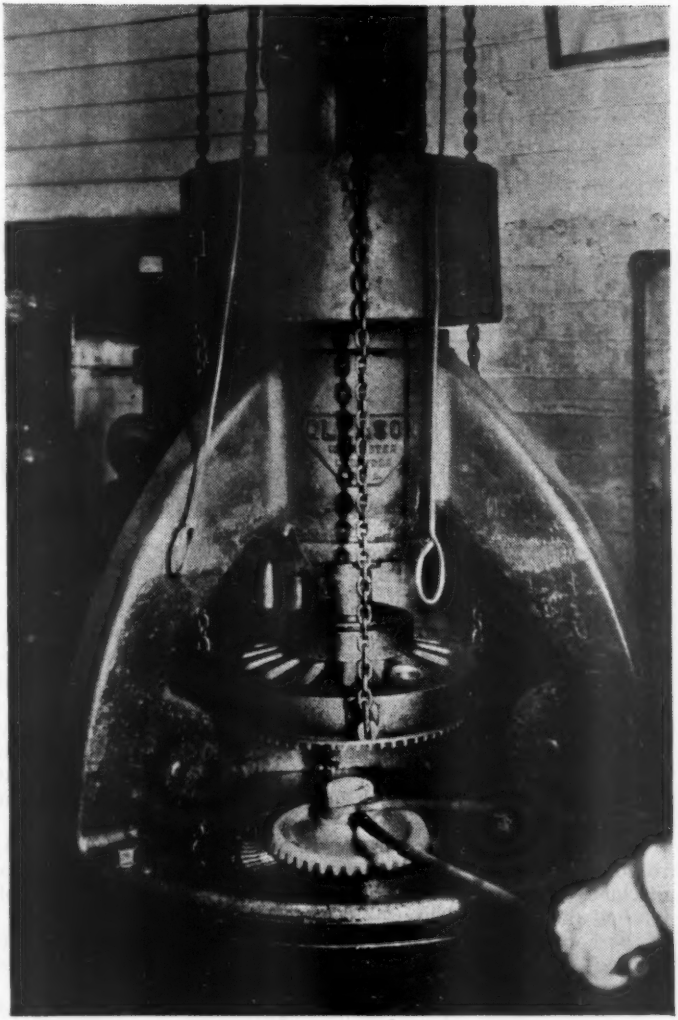

FIG. 4. Hydraulic quenching press.

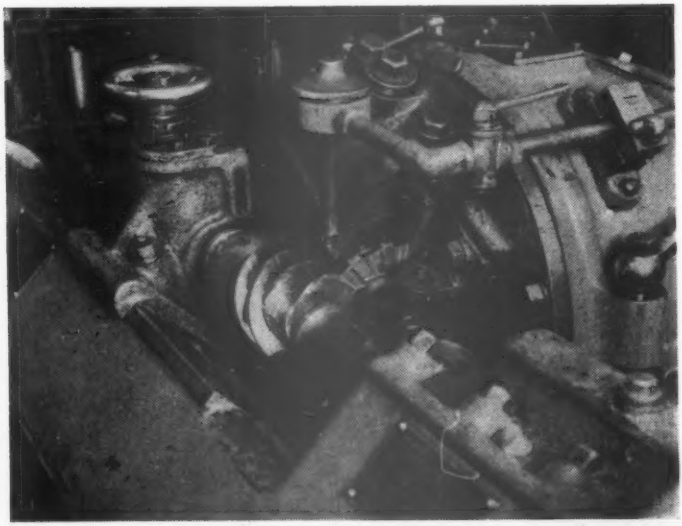

FIG. 5. Worm milling machine.

Sunderland, who were responsible for the plano-generating machine bearing their name, which has, for many years, been made by Parkinsons of Shipley. This employs the straight sided rack cutter and is probably the most direct method of generating spur and helical gears.

Fellows type machines have long been in use for generating the tooth form from a cutter having the shape of a pinion, with which the blank is rotated during the process. The cutter itself is generated from an abrasive wheel, which takes the form of a straight sided rack tooth.

The machines developed by W. E. Sykes, and named after him, combine most of the advantages of the Sunderland and Fellows machines and are particularly suited to quantity production of internal and external gears.

The hobbing process is the most commonly used where extreme accuracy is required and many names are associated with its development.

As far back as 1900, J. E. Reinecker, of Chemnitz, manufactured universal gear cutting machines, similar in principle to some of the more modern machines made by such firms as Muir, Craven, Pfauter and Gould and Eberhardt, which will cut spur wheels, helical

and worm wheels, either with axes at right angles or inclined at any other angle between, say, 90 and 60 degrees. The indexing can either be continuous, using a hob, or intermittent and hand-operated using a rotary cutter operating on one tooth space at a time.

In the hobbing process, feed can either be parallel with the axis of the wheel being cut or tangential for use in cutting worm gears. Further remarks regarding the hobbing process will be given later in the lecture.

As hardened gears carrying heavy loads came more and more into use, the demand for quiet running and accuracy of contact to give maximum load capacity made it necessary to introduce means for eliminating the effects of distortion which occur in hardening. Profile grinding of the teeth was a natural development in this direction.

In the case of large quantity production as, for example, in the automobile industry, the operation of grinding has been found to be relatively expensive and means have been sought to eliminate this process by :—

1. Improving the quality and structure of stampings and using steel of controlled grain size.

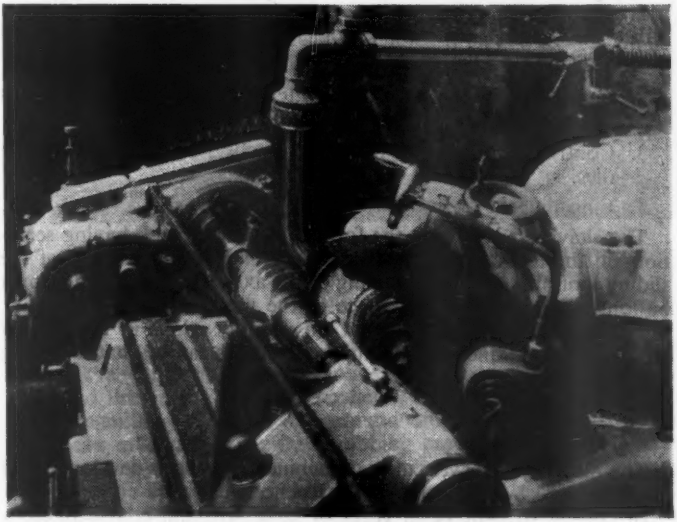

FIG. 6. Hydraulic worm grinder.

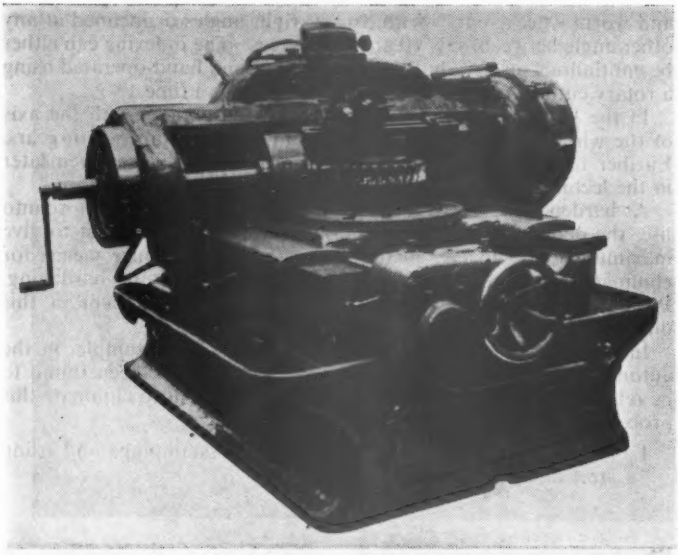

FIG. 7. Wormwheel hobbing machine.

2. Improving the tooth form and pitch by adoption of the crossed axis shaving process after cutting.
3. Controlling distortion in hardening by the use of quenching dies.
4. Finishing the teeth by crossed axis lapping.

The shaving cutter is in the form of a gear or rack having serrations in the teeth which affect a cutting action as the result of the sliding motion due to the crossing of the axes. The rack cutter must be longer than the circumference of the gear to be shaved and is, therefore, an expensive tool, but this is not serious in the case of repetition work, since a large number of gears can be shaved during its life.

Bevel Gears.

The majority of bevel cutting machines have been developed and manufactured by Gleason Works, Rochester.

In cutting straight bevel gears of large size and coarse pitch, a planing process is generally used, in which a single point tool is

guided, by means of a shaped cam, but for smaller gears, where quantity production is required, automatic machines are now in use, employing two single point cutters operating on a generating principle.

There are a number of methods in use for cutting spiral bevels, the choice between the methods adopted in any particular case being dependent on the quantity and quality of work required. Bevel wheels are usually generated by the spread blade method, in which both flanks are cut simultaneously, the rotary cutter having alternate inside and outside cutting blades. For high quality production, bevel pinions are usually finished on each flank separately and often on two fixed setting machines. This method enables any desired contact between the gears to be obtained.

Simpler methods are sometimes used for quantity production, but these generally involve some sacrifice in accuracy of shape.

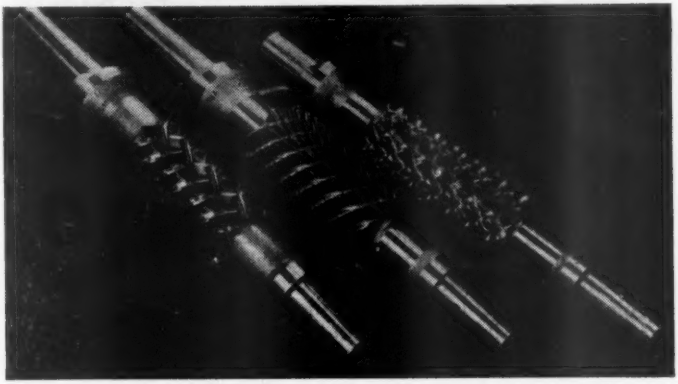

FIG. 8. Roughing and serrated finishing hobs for wormwheels.

Worm Gears.

The development of worm gears and worm gear cutting and finishing machines has long been one of the most important activities of David Brown & Sons (Huddersfield), Ltd. Worms are rough cut in worm milling machines and ground after hardening. When the quantities involved justify it, a hobbing process can sometimes be used with advantage for cutting, and recent machines for milling and grinding employ the latest refinements of hydraulic operation.

Worm wheels are usually cut on hobbing machines having tangential feed and a tapered hob. Owing to the relief required on

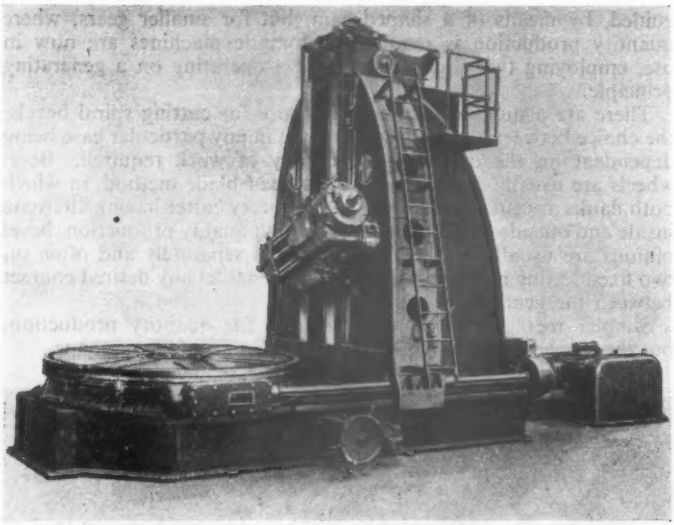

FIG. 9. Large hobbing machine.

the hob teeth, the diameter of the finishing end of the hob is reduced each time it is sharpened and, for this reason, serrated finishing hobs are often employed, to give the final correction to the shape of the worm wheel teeth.

Considerable skill is required in the design and use of these hobs to achieve the desired contact with the mating worm.

The final drive to the table of many gear cutting machines is obtained through worm gears which must, in consequence, be of the greatest possible accuracy.

Double Helical Gears (Hobbing Process).

A brief reference has been made to one or two types of machines suitable for cutting double helical gears and it is proposed to deal a little more fully with the hobbing process, which is used very extensively for the cutting of high-speed turbine gears and involves a specially high degree of precision. The type of machine used will also cut straight spur wheels and worm wheels, but it is of special interest as a machine for producing accurate helical gears which are commonly made for peripheral speeds of 12,000 ft. per minute and, in special cases, about 20,000 ft. per minute.

One of the most difficult and urgent problems of the present day in the gear cutting world is the attainment of the requisite accuracy in hobbing machines for such gears. This depends on many factors, the most important of which are :—

(*a*) accuracy of hob ;

(*b*) correct mounting of the hob on a true running spindle ;

(*c*) the uniformity of relative motion between the hob spindle and the work table ;

(*d*) the precision of the feed screw actuating the hob saddle.

Minute errors arising from the index gear and the feed screw produce wave errors on the gear teeth. Those arising from the feed screw will reduce the available tooth contact, but may not give noisy running, while those arising from errors in the index gear will generally give both restricted contact and a lesser degree of quietness than is obtained if no such error exists. The pitch of the waves previously referred to depends on the pitch of the master wheel and it is now generally recognised that relatively fine pitch master wheels are necessary for this work.

Shaving Process.

Wave errors arising from hobbing machine inaccuracies can be reduced by the shaving process, which was mentioned previously in connection with spur gears, provided that the pitch of the waves in a direction along the helix is not too large.

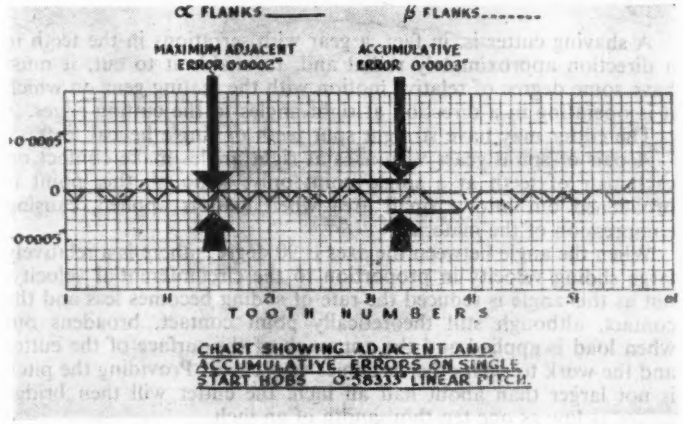

FIG. 10. Chart showing adjacent and accumulated errors on single start hobs.

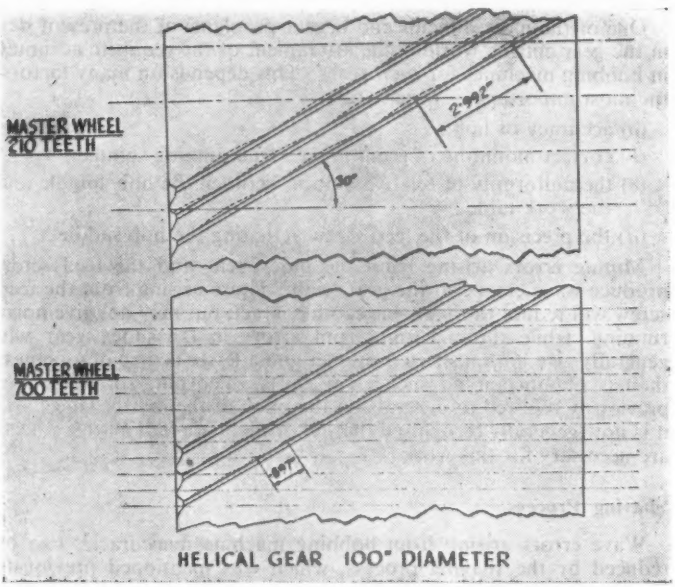

FIG. 11. Diagram showing relation between the number of teeth in master wheel and the pitch of undulations.

A shaving cutter is, in fact, a gear with serrations in the teeth in a direction approximately radial and, to enable it to cut, it must have some degree of relative motion with the mating gear on which it is operating in a direction at right angles to the cutting edges.

The cutter may have straight spur teeth or single helical teeth.

A pair of spiral gears with axes at right angles make contact on each pair of teeth at a single point only, although this point is broadened out into a small area when load is applied, causing compression of the material.

When the angle between the axes is 90 degrees there is a relatively large sliding velocity in proportion to the circumferential velocity, but as this angle is reduced the rate of sliding becomes less and the contact, although still theoretically point contact, broadens out when load is applied and the approach of the surface of the cutter and the work to each other becomes very close. Providing the pitch is not larger than about half an inch, the cutter will then bridge waves as low as one ten-thousandth of an inch.

The most suitable angle between the axis of the gear and the axis

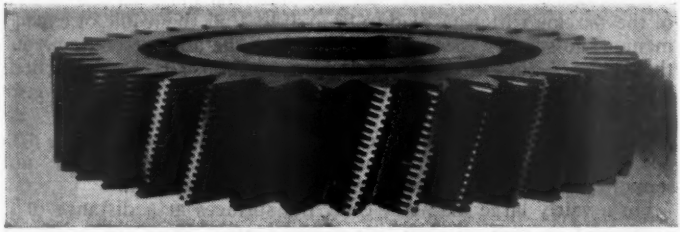

FIG. 12. Shaving cutter.

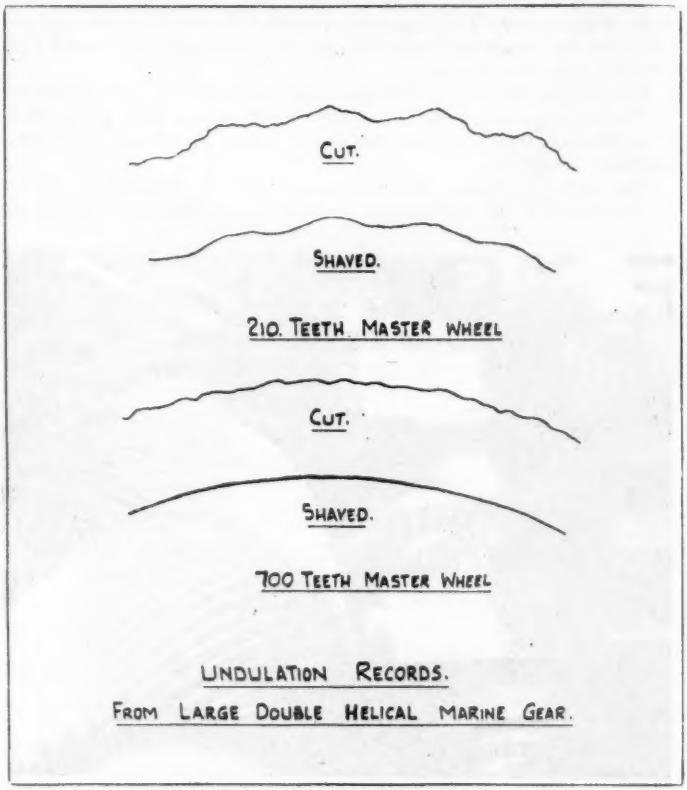

FIG. 13. Undulation records.

of the shaving cutter has had to be arrived at as the result of experiment. The smaller the angle, the broader the area of contact, but the less free is the cutting action and a compromise has to be reached. The usual angle of axis between a shaving cutter and its mating gear is approximately 15 degrees.

While the cutter is in theoretical contact in one plane only, it is not a difficult matter to calculate by how much the surfaces are separated at planes on each side of the contact position.

On a fairly large diameter gear, the surfaces at a distance of a quarter of an inch on each side of the contact plane are separated by considerably less than one ten-thousandth of an inch, so that when load is applied, cutting will take place on a band more than half an inch wide. The action of shaving will tend to correct errors of shape and pitch and errors by which a tooth departs from a true straight line or a true helix.

The latter type of error has just been referred to as a wave error.

The shaving cutter is not controlled in any way, except by the gear it is shaving, which acts as the driver. It is, in effect, a machine-operated scraper.

The shaving process probably originated in this country about 30 years ago in its application to worm gear manufacture, but its

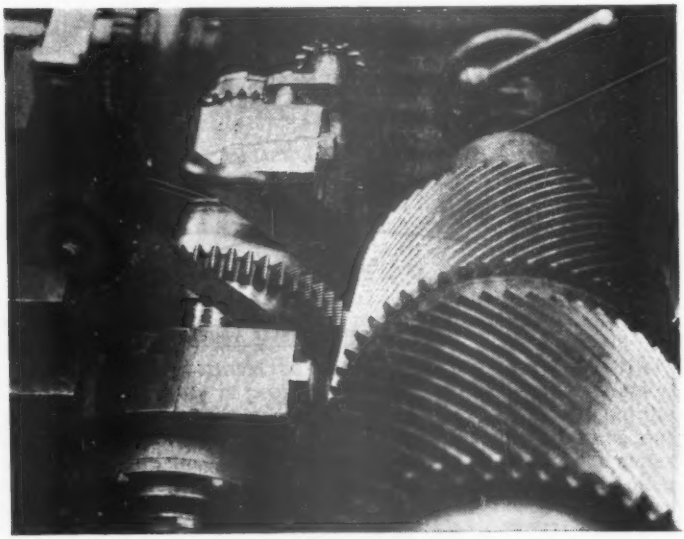

FIG. 14. Turbine gear pinion set up for shaving.

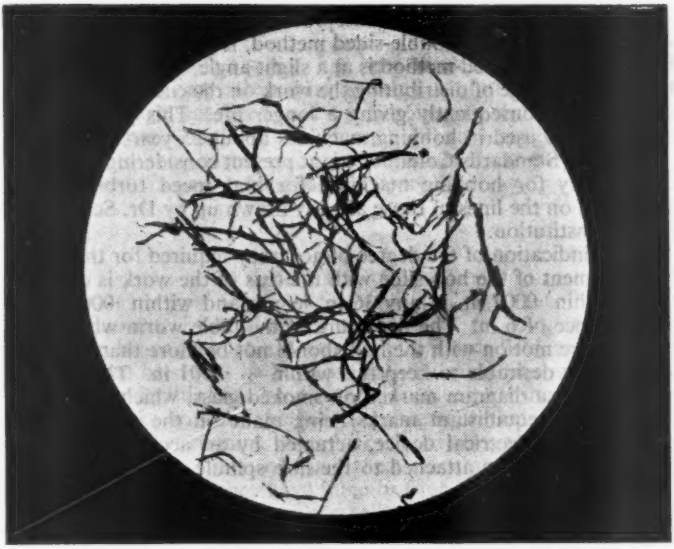

FIG. 15. Chip formation produced in shaving.

development in connection with spur and helical gears took place mainly in the United States, although the method had been proposed in this country some time before.

Experiments on its application to turbine gears have been in process here for the past six years and have differed from the American procedure in two important respects.

American practice has been to apply the load to the cutter by closing the centre distance and thus cutting on both flanks of the teeth simultaneously.

In experiments at David Brown & Sons (Huddersfield) Ltd., this method has not been used, but the alternative method has been favoured, of cutting on one side of the tooth only, using a band brake on the cutting arbor to apply the load.

The double-sided method must always remove metal on both sides of the teeth of about the same amount, but the single-sided method can be used effectively to improve contact on either flank after a preliminary marking, by taking extra cuts at the places where marking is heaviest. The amount of cut taken at each pass is very small (about one ten-thousandth of an inch), but a definite chip is formed.

The other respect in which the practices differ is in the direction of feed, which, in the double-sided method, is parallel with the axis, but in the single-sided method is at a slight angle. The latter method has the advantage of distributing the work on the cutter over a much wider band, consequently giving a longer life. This practice is in line with one used in hobbing machines about 25 years ago.

A British Standards Committee is at present considering standards of accuracy for hobbing machines for high-speed turbine gears, somewhat on the lines of those already drawn up by Dr. Schlesinger for this Institution.

As an indication of the degree of accuracy required for this work, the alignment of the hob slide with the axis of the work is expected to be within ·0007 in. in any 36 in. length and within ·0002 in. in any distance of 6 in. The departure of the table worm wheel from true relative motion with the hob should not be more than $\pm$ ·0002 in. and it is desirable to keep this within $\pm$ ·0001 in. This error is measured by a diagram marked on smoked glass, which is attached to the table, equidistant marks being made on the smoked glass record by an electrical device, actuated by an accurately divided notched index plate attached to the hob spindle.

Other Current Developments.

Time does not permit of a detailed description of the many other developments now taking place in gear cutting technique, but these may be referred to in general terms under two main headings :—

(*a*) *Modification of Tooth Form.*

For many years the ideal to aim for was considered to be the theoretically true involute tooth, giving as nearly as possible uniform load over the tooth face. It is now realised that, for heavily loaded gears, tooth load should be confined to the central area of the teeth and relieved from the ends and tips of the teeth. This result is obtained by the use of hobs, cutters or grinding wheels having modified profiles, and paralleling the teeth in the finishing processes.

(*b*) *Increased Rate of Cutting.*

Efforts are being made to apply to gear cutting the experience gained in the use of carbide tipped cutting tools in simpler machining operations. The problem of manufacturing carbide tipped hobs is not an easy one, however, and existing gear cutting machines are not suitable for the increased speeds and loads. Special machines will, therefore, be needed, which can meet these requirements while satisfying the incessant demand for still greater accuracy.

Conclusion.

Although the review which has been made of past and present developments in gear cutting and finishing is, of necessity, somewhat sketchy, enough has been said to demonstrate the rapid progress which has been made in this branch of engineering and, more especially, in that branch of the machine tool industry on which developments in gear cutting largely depend.

DISCUSSION.

MR. BLORE: First of all, I should like to congratulate Mr. Everest on his paper; he has covered a very wide field, and our only difficulty has been that he has gone rather deeply into mathematics, which, I am afraid, have been rather too much for most of us.

I would like to ask whether the statement that "tip relief is essential for quiet running gears" is true of all types of gears. This is surely limited to gears of the highest class, and I am aware that on gears of this type they have three or four degrees off.

When the lecturer first began to talk about shaving, I got the idea that it was a case of pushing up rates of production, but I changed my ideas later on. I would be interested to know whether equal accuracy could be obtained by more care in the hobbing process.

I should be glad if the lecturer would give some information indicating how the metallurgist reconciles the refinements of modern gear cutting with the crude process of hardening in which the gears are put into the fire, clamped in a die, and thereby subjected to more stress and distortion than ever before.

MR. EVEREST: The ability to obtain tip relief has been claimed as one of the advantages of form grinding as compared with the generating processes, and this more obviously applies to hardened and ground gears, presumably of high class. B.S.S. 436 calls for tip relief, however, even on unground gears, and such profile modification is undoubtedly advantageous for almost every class of gear, although it will obviously have little influence on the problem of noise in the case of very slow running gears. The present trend is towards an increase in the amount of tip relief provided on gears, particularly of the highly loaded or high speed types.

Mr. Blore is probably correct in his suggestion that accuracy equal to that of a shaved gear could be obtained by hobbing alone, but this is largely a question of economics, since the relatively inexpensive shaving machine will do in a few minutes what might take an expensive precision hobbing machine a matter of hours.

The criticism raised against the older methods of carburising and

heat treating gears in a furnace are, to some extent, justified, and distortion resulting from such treatment has been a very difficult problem to solve. There are several alternative methods of case hardening and heat treatment which are slowly replacing the older method.

The condition of the steel, as supplied by the steel manufacturers, has an important bearing on this problem, however, and although there has been difficulty during the war in obtaining steel of suitable grain size and grain flow, there is every hope that before long it may be possible to obtain steel blanks to a precise specification in these respects.

MR. JEFFERIES: May I ask the lecturer if anything has been done in the last few years whereby the hob, instead of travelling straight across the gear, is made to precess across the face of the gear by setting the hobbing head at an angle?

MR. EVEREST: No, it is not believed that this method has been incorporated in hobbing machines in recent years, although one or two machines were designed and manufactured by David Brown & Sons about 20 years ago which operate on this principle.

The only advantage lay in the transference of load across the face of the hob. To offset this, however, the change wheel calculations were considerably complicated, and problems affecting the length of hob and width of gap for double helical gears were also introduced.

In the case of the shaving machine, the feed motion of the shaving cutter across the face of the gear is slightly at an angle, in order to distribute the cutting load across the face of the shaving cutter. In this case there is a considerable advantage, since in the crossed-axis method of shaving the actual cutting is restricted to a band of less than $\frac{1}{2}$ in., no matter what the width of the shaving cutter.

MR. HALL: May I ask the lecturer what has been his experience of cutting fluids? I am concerned with high-speed turbine gears, and there is a tendency to use water compounds. Is this detrimental to the machine?

Also, with regard to turbine gears, I am having severe headaches with shaving up to 48 in. diameter and was staggered to receive a suggestion that we might be required to do some further processes after shaving on turbine gears, although we have no visible undulation.

With reference to a previous question, I had one of Churchill's representatives along a fortnight ago and he was complaining that he had a new gear hobbing machine from the States, where the hobbing head was traversing across the surface of the gear. He was not in favour of it.

MR. EVEREST: Dealing with the last part of the question first, the American hobbing machine referred to is probably one of the small production machines designed with the hob slide parallel to the axis of the table, but fitted with an additional motion whereby the hob is automatically fed in a direction tangential to the gear blank, at the same time as it traverses the gear face.

This is an alternative method of achieving the same result as with an inclined hob slide, and the difficulties regarding the change gear calculations, etc., are substantially the same.

In selecting cutting fluids, there are two main requirements to consider; one is lubrication and the other is cooling, and in cutting any particular gear it must be decided which is the more important factor. For very heavy roughing cuts, cooling is the more important consideration and the fluid must, therefore, be predominantly water, as this is the best coolant. For light or finishing cuts, as employed for turbine gears, the principal factor required is lubrication and a good cutting oil is therefore used, with little or no water. Between these two extremes, there are applications for mixtures of soluble oil and water in various proportions.

In addition to the question of cooling and lubrication, however, there is a third important problem, namely, the corrosive effect of the cutting fluid on the working parts of the machine itself. Thus, although there may appear to be little to choose between various proprietary makes of cutting fluid, experiments show that there is a great difference between them in this corrosive effect, and this will, therefore, have considerable bearing on the selection of particular cutting oils.

Mr. Hall's reference to post-shaving processes presumably refers to lapping, which is extensively used in the U.S. and to a lesser degree in this country. Lapping can effect certain improvements in gear teeth, mainly as regards surface finish. The process can, however, have very detrimental results in other respects, and if carried too far will tend to destroy, rather than improve, the involute tooth form. This arises from the obvious fact that the lapping action will vary over the tooth profile according to the ratio of sliding to rolling at each particular point.

In the case of soft gears, experience has shown that it is almost impossible to remove completely the lapping compound, some of which remains embedded in the tooth flanks. Lapping certainly produces a very fine finish and polish on the teeth, but it is probable that with improvements in hobbing and shaving machines, the lapping process will be applied less frequently.

FOURTH QUESTION: Why should it be considered necessary to depart from the true involute form?

MR. EVEREST: Generally speaking, the answer is to prevent tip

interference in the running of gears. Due to the deflection of the gear teeth under load and possible slight errors of pitch, the tip of the teeth will tend to strike first and thus cause noisy running.

In addition, the effect of tip interference is to produce shock loading on the teeth and the scraping action of the tip tends to break down the oil film and thus initiate failure of the tooth flanks. Hence, it is desirable for all normal gears to modify the profile from the true involute towards the tip of the tooth so that the load is taken up gradually as each tooth comes into mesh.

MR. BROWN: I should like to ask Mr. Everest a question about lapping. In the illustration we saw three gears shown as the lapping medium. Would it not have been advantageous to employ the crossed-axis principle here, as in the shaving process, in order to get sliding action across the tooth?

MR. EVEREST: The particular machine which was shown does actually work on this principle, the three laps being set at an angle so as to give the desired cross sliding action.

There are other lapping processes such as the American "Incolap," for instance, where the motion is entirely across the face of the gear. In this process a lap is used in the form of a cast iron internal gear, and the work gear is reciprocated axially through the lap, pressure being applied alternately to each flank. The gear is frequently withdrawn from the lap and re-entered in a different position of mesh so as to average out the pitch errors.

MR. PHILLIPSON: I should like to say how much I have enjoyed Mr. Everest's lecture. There is one point I should like to raise, about which there is a certain amount of controversy, and this relates to methods for obtaining the correct pitching of master indexing wormwheels.

We have been trying to obtain correct indexing by means of a template, but we are told by the makers that we cannot expect a better degree of accuracy than eight thousandths of an inch accumulative error, which is very different from what Mr. Everest has told us to-night. I have been trying to use a split master wheel, and I should like the lecturer's further remarks about how he obtains the correction. Is the split wheel turned through 180 degrees?

MR. EVEREST: The production of accurate dividing wheels is merely a question of intelligent "breeding," and the application of split master wheels.

The new master wheel is first cut on the best machine available, and the pitch errors of the teeth carefully measured and plotted for the complete circumference. The two halves of the split blank are now turned so as to bring the peaks in the pitch curve for one half

opposite the valleys in the other, thereby approximately halving the accumulative pitch error. The angle through which the half wheel is turned will depend entirely on the shape of the pitch error curve and will not necessarily be 180 degrees.

The master wheel is now given a finishing cut with the hob free from axial constraint so as to act as a mechanical scraper. A further pitch test may then indicate the desirability of again turning one half of the wheel relative to the other in order to obtain a further reduction in pitch error. In this way, the errors of pitch can be reduced successively in magnitude until the best result is obtained.

The greatest difficulty in applying this method arises from the turned spigots, which must locate the two halves while at the same time permitting them to be freely separated and rotated into any desired angular position.

MR. GAZARD: It appears that the accuracy we can obtain is entirely the responsibility of the machine builder who uses a train of gears. In the Maag principle one entirely eliminates the action of gears, yet apparently we avoid that method at the moment.

With regard to form hobs, some time ago a method of straight-line relief for the finishing of hobs was developed. Has this gone underground in this country? What are your opinions about this?

The question of the holding of gears during cutting seems to be one of the criteria for obtaining accuracy, and more improvements can be made in machines for locating the work.

In cutting very small gears, one method we found very successful was to cut a stack of gears mounted on a common mandrel and thus hob several gears at one setting. We have also found it advantageous to finish-bore small gears by holding them in a chuck locating from the gear teeth.

MR. EVEREST: Although in the planing process the cutter is given a straight-line reciprocating motion, this will of course be mechanically synchronised with the rotation of the gear blank through a train of gears exactly as in the case of hobbing machines, otherwise correct generating and pitching of the teeth would not be obtained.

The planing process is, however, not applicable to high accuracy gears, due to the intermittent nature of the indexing and difficulties associated with the reciprocation of a massive cutter head. It is very much easier to build and maintain a hobbing machine dependent only on rotating parts, and for this reason the hobbing process is unrivalled for precision cutting.

Straight-line relief has been applied in the finishing of hobs, but it offers little advantage over other forms of relief which are more convenient to manufacture. The ideal form is, of course, that in

which the relief angle remains constant as the tooth is sharpened back, but this is not readily obtainable in practice.

The cutting of gears in clusters is undoubtedly an economical production method where the design of the gear permits this method of mounting. It is often not possible to confine the gear boss to within planes containing the end face of the gear rim, but provided one end of the boss complies with this requirement, it is always possible to cut two gears mounted together.

The method of holding the gear in the " pitch line chuck " is a recent development which undoubtedly is of assistance in obtaining finished bores accurately concentric with the teeth themselves, and independent of any slight errors in concentricity of the outside diameter or other reference diameter previously employed for chucking purposes.

MR. SIDDALL: It gives me very great pleasure to move a vote of thanks to Mr. Everest for his lecture to-night. I feel that I am speaking for all when I say that he has covered the ground as well as he could in the short time available for such a subject.

MR. EVEREST: I am very grateful for Mr. Siddall's kind words of appreciation, and for the keen interest which you have displayed in my lecture. It is very gratifying indeed to have had so many pertinent questions asked.

Research Department : Production Engineering Abstracts

(Prepared by the Research Department.)

NOTE.—*The Addresses of the publications referred to in these Abstracts may be obtained on application to the Research Department, Loughborough College, Loughborough. Readers applying for information regarding any abstract should give full particulars printed at the head of that abstract including the name and date of the periodical.*

HEAT TREATMENT.

How to Design Coils for Induction Heating, by Frank W. Curtis. (*The Machinist*, 18*th May*, 1946, *Vol.* 90, *No.* 6, *p.* 201, 9 *figs.*)

Coil making necessitates a full consideration of the fundamental requirements. These are explained and practical examples are illustrated.

COOLANT, LUBRICANT.

Cutting Fluids, by J. C. Zelenka. (*Mechanical World*, 24*th May*, 1946, *Vol.* 119, *No.* 3099, *p.* 569.)

The two main functions of coolants are: good lubrication and efficient cooling, which are largely interdependent. These and other effects are illustrated by reference to turning and drilling. Cutting fluids increase tool life, improve finish, help to maintain size, and reduce the power required. Cutting fluids can broadly be divided into soluble oil emulsions and straight cutting oils and the ranges of applications of each are indicated, with recommendations for the best practice.

Characteristics of Coolants and Cutting Fluids, by J. R. Chambers. (*Machinery*, 9*th May*, 1946, *Vol.* 68, *No.* 1752, *p.* 597.)

Cutting fluids are used (*a*) to dissipate the heat generated by the cutting operation ; (*b*) to eliminate friction ; (*c*) to provide a good finish ; and (*d*) to wash away chips. In selection, safety features should be considered, e.g. flash point, dermatitis prevention and odour. Coolants may be divided into three main classes: soluble oils, base oils, and mineral oils, and these are defined and their properties and respective scopes are indicated. Recommendations are given for the machining of steel and cast iron, brass, aluminium alloys, and magnesium alloys.

EMPLOYEES, APPRENTICES.

Apprenticeship Training for the Machine Tool Industry, by H. Teasdale. (*The Machinist*, 4*th May*, 1946, *Vol.* 90, *No.* 4, *p.* 121, 2 *figs.*)

Part II. The technical education of the apprentice must be judiciously planned. The author criticises the academic tradition in our technical education system and suggests that workshop technology should be compulsory for the first three years of the National Certificate course. Five desirable subjects are: mathematics, engineering science, engineering drawing, workshop technology and English, and the scope of each is discussed. A five-subject three-year National Certificate course could easily be managed on one full day and two evenings

per week. Optional subjects would include further mathematics, metrology, machine tools, jig and tool design, hydraulics, electro-technology, heat engines, aeronautics, plastics, press-tool technology, theory of machines, strength of materials, the fundamentals of industrial administration and a foreign language for those suitable for promotion later to higher posts.

Basis of Wage Payment, by Gordon Lowe. (*Mechanical World*, 3*rd*, 10*th*, 17*th May*, *Vol.* 119, *No.* 3096, 3097, 3098, *pp.* 485, 515, 559, 2 *figs.*)

Part 1. Piecework and time rates are dealt with in a preliminary consideration of what wages mean.

Part 2. The disadvantages of time work and the features of individual and group incentives are compared. The origins of scientific management are described.

Part 3. Differential piecework systems as used by Taylor, Gantt, Emerson, Halsey and Rowan are briefly compared.

Plain Facts on Productivity. (*Mechanical World*, 31*st May*, 1946, *Vol.* 119, *No.* 3100, *p.* 621.)

Six reasons for the widespread indifference to the quantity and quality of work done are: tiredness and reaction resulting from the strain of the war; the effect of the Essential Work Orders; the pay-as-you-earn system of taxation; the tradition against high out-put; the antagonism to the profit motive; and the divorce in the minds of most people between wages and real wages. The last point is discussed at length.

MACHINE ELEMENTS AND DESIGN.

Sound Proofing, by Dr. N. Fleming. (*Mechanical World*, 10*th May*, 1946, *Vol.* 119, *No.* 3097, *p.* 519.)

The principles of preventing the transmission of machinery noise are discussed, with particular reference to sound proofing in aircraft, but they can be applied to other spheres.

MACHINING, MACHINE TOOLS.

Specialized Machine Design Facilitates Production of Machine Tool Castings, by G. C. Gilbert. (*The Machinist*, 25*th May*, 1946, *Vol.* 90, *No.* 7, *p.* 231, 8 *figs.*)

By employing machines of special design and appropriate fixtures, the handling time for the production of large column castings for milling machines was reduced to 11 per cent. of the total machining time.

Form Grinding by Crush Dressing, by C. Linxweiler. (*Machinery*, 2*nd May*, 1946, *Vol.* 68, *No.* 1751, *p.* 553, 14 *figs.*)

Some new developments are described.

Alignment Chart for Cutting Speed, by F. Jones. (*Machinery*, 9*th May*, 1946, *Vol.* 68, *No.* 1752, *p.* 602.)

The factors in alignment are diameter, peripheral feet per minute, and revolutions per minute.

CHIPLESS MACHINING.

Pressed Pistons for Heavy Duty Diesel Engines, by L. P. Gibson. (*Engineering Materials*, *April*, 1946, *Vol. IV*, *No.* 2, *p.* 316, 4 *figs.*)

This article first discusses factors affecting piston endurance. The properties required from piston materials are: low specific gravity, good heat conduction

and wear-resisting properties, high strength at elevated temperatures and low coefficient of expansion. Suitable materials include "Y" alloy and 12 per cent. silicon aluminium alloy or "Lo-Ex," the properties of which are compared. The fundamental differences between a cast and a pressed piston are briefly described. Methods of working stock prior to pressing include the hammering and extruding of the cast billets. During manufacture a heat-treated sample piece is tensile tested and a further specimen is macro-etched for examination of the grain size and general structure of the material. The bar is cut to a predetermined length and the billet is then preheated after being pre-worked or pressed in the cast or extruded condition. For pre-heating resistance furnaces and salt baths are employed and induction heating will reduce the time lag for pre-heating if it can be successfully introduced. The normal pre-heating temperature range is about 470°C. When the billet has soaked for a sufficient length of time it is pressed to the final shape under a 1,000-ton hydraulic press. Moving cross-heads are fitted to the presses and a two-stage pressing can be made at one setting without the need for reassembling a new punch head and a second pre-heat for the billet. The press tools are made of hot die steels containing 10 per cent. tungsten, substitute 1 per cent. tungsten steel or nickel-chrome molybdenum. More than 50,000 pressings for a 600 h.p. heavy-duty diesel tank engine have been made from a punch head, 80,000 pressings have been produced from a single base plate made from nickel-chrome-molybdenum steel, and more than 120,000 have been produced from the same nickel-chrome-molybdenum steel liner. After removal from the press, the piston blanks are trimmed and passed to the heat-treatment section. Samples selected at random are examined by the laboratory.

MANUFACTURING METHODS.

Modernisation in the Reconversion of Engineering and Shipbuilding Workshops, by Dr. H. Orenstein. (*Mechanical World, 19th April,* 1946, *Vol.* 119, *No.* 3094, *p.* 427, 6 *figs.*)

This is a detailed abstract of a paper presented to the Institution of Engineers and Shipbuilders in Scotland and deals with the principal problems and solutions of mass, batch, and individual production methods. The reconversion of a works or shipyard involves equipment, layout, organisation and costing and it is necessary to determine the operations for machine tools and equipment, estimate time required for each operation, prepare a preliminary layout, prepare a detailed specification, design and specify tools, gauges and fixtures, determine methods of storing and handling materials, make the final layout of all machine tools, conveyors, heat-treatment furnaces, stores, etc. For mass production there are two distinct methods of machine layout, namely, process or functional layout and product or straight line layout. In process layout there is lower investment in machines, lower manufacturing costs and no hold up of a succession of operations through equipment failures. More difficulty is experienced in routing and scheduling, more floor space is occupied per unit of product, more hand labour is involved, total time of production is greater on account of transportation, more complicated production control, and more training is needed to develop workers.

Time Study and Rate-fixing, by P. M. Garnier. (*Machinery, 16th May,* 1946, *Vol.* 68, *No.* 1753, *p.* 632.)

The author critically reviews the treatment of fatigue and wage payment problems in a number of well-known publications.

MEASUREMENT, INSPECTION.

Pneumatic Gauges, by H. Niepel. (*Mechanical World*, 17*th May*, 1946, *Vol.* 119 *No.* 3098, *p.* 545, 9 *figs.*)

The principles are developed on a thermodynamic basis and attention is drawn to the influences of temperature, nozzle cross-sections, nozzle contraction coefficients, supply pressure, indicating pressure and atmospheric pressure. In the application of these principles pneumatic gauges can be sub-divided into three groups: (1) Measuring instruments in which a hole to be measured is used as exit nozzle of the gauge. In spite of the low degree of sensitivity, preference is given to this method for measuring small holes as it uses simple means and avoids any mechanical damage. (2) Measuring instruments with direct use of the air jet and in which the part to be tested is not in contact with the measuring nozzle. Wear of or damage to gauge and work pieces are as far as possible avoided and the high entrance pressure causes a cleaning action. For measuring holes above 1·5 mm. diameter gauge pins are used which have two or more nozzles on their periphery. If two opposite measuring nozzles are applied, the gauge can be used for measuring eccentricity and taper of holes. If two measuring nozzles are arranged at a constant distance so that the part to be measured can be placed between them, it is possible to measure thickness variations of films, paper, or foil. A device for measuring the cross-sections of wires or textile threads can be used for running production measurement. Balls used in ball-bearing can also be measured. (3) Measuring instruments with a mechanical member which comes into contact with the part to be tested. Such gauges are comparable in their sensitivity with optical, mechanical, and electrical pressure measuring devices.

Measurement by Electronics. (*The Machinist*, 18*th May*, 1946. *Vol.* 90, *No.* 6, *p.* 193, 5 *figs.*)

In general, the principle of an electronic measuring instrument is to use the material under test in such a way that it alters the characteristics of a circuit operating at radio frequencies. It is possible to cause a variation either in voltage amplitude or in frequency, i.e., to employ either amplitude or frequency discrimination. In a radio frequency crack detector using the former, the material to be tested is passed through the inductance of an oscillatory circuit, and the frequency is selected to give a depth of current slightly deeper than the deepest crack to be measured. The effect with a sample which is free of cracks is that of a short-circuited turn. If a crack is present, an increase in oscillator inductance will be caused and the frequency will drop. The variation in frequency has the effect of causing a large variation in output voltage, which is applied to a suitable indicating instrument. The voltage will be proportional to the depth of crack and a meter can thus be calibrated to indicate depth. An electronic comparator employs the frequency discrimination principle. The material under test forms part of the oscillator circuit. The variation of the test piece alters the characteristic of the oscillatory circuit and thus causes a variation, the result of which, after amplification, is applied to a measuring instrument to give visual comparison. A portable model weighing only a few pounds has been applied to: dimensional checks to 0·000,000,01 in., physical, analytical, and chemical comparison of material, hardness testing, checking of heat treatment, tensile strength, compression strength, elongation tests, bend test, fibre tests, paint thickness tests, base metal tests, engine tests, gas purity tests, vibration tests up to 1 mcs. and 1 micro-in., surface measurement, pressure tests and metallic film thickness measurement on resilient non-metallic bases from a fraction of 1 micro-in. to approximately 0·001 in.

Magnetic Inspection Procedure, by E. D. Wilcox. (*Machinery*, 18*th April*, 1946, *Vol.* 68, *No.* 1749, *p.* 489, 9 *figs.*)

This article explains the principles of magnetic inspection for the benefit of those not familiar with this process and describes, in detail, the procedure followed.

Inspection Operations on Jig-boring Machines, by J. R. Moore. (*Machinery*, 16*th May*, 1946, *Vol.* 68 ,*No.* 1753, *p.* 617, 7 *figs.*)

Feasibility, accuracy, and economy are claimed for inspection of jobs in jig-boring and jig-grinding machines. Typical inspections are described.

PLASTICS.

The Location of Inserts for Plastic Moulding, by H. Pry. (*Machinery*, 9*th May*, 1946, *Vol.* 68, *No.* 1752, *p.* 593, 11 *figs.*)

Some common faults in bush-type and pin inserts are shown and better designs are described.

SHOP ADMINISTRATION.

The New Income Tax Allowances on Industrial Buildings, Machinery and Plant, and Patents. (*Mechanical World*, 10*th May*, 1946, *Vol.* 119, *No.* 3097, *p.* 536.)

Features of the new system now in operation.

SMALL TOOLS.

The Accurate Production of Spiral Mills, by K. S. Molnar. (*Machinery*, 18*th April*, 1946, *Vol.* 68, *No.* 1749, *p.* 497, 11 *figs.*)

The influence of helix angle and other design factors are first discussed. The geometrical development of the necessary fluting cutter profiles is then given in detail, with special attention to the avoidance of back cut.

Wedged and Clamped Tip Carbide Tools, by N. E. Hodge. (*Machinery*, 2*nd May*, 1946, *Vol.* 68, *No.* 1751, *p.* 561, 3 *figs.*)

Considerable advantages are claimed for this type in comparison with brazed tools.

Cushioned Tips Extend Life of Negative-Rake Turning Tools, by W. C. Holloway. (*The Machinist*, 25*th May*, 1946, *Vol.* 90, *No.* 7, *p.* 242, 4 *figs.*)

When such tools are removed from the machine, they are more likely to be dull than chipped, and losses in grinding are negligible.

WELDING, BRAZING.

Electric-furnace Brazing, by H. D. Hendrick. (*Machinery*, 9*th May*, 1946, *Vol.* 68, *No.* 1752, *p.* 585, 7 *figs.*)

The application of furnace brazing as a production line process is described.

WORKS AND PLANT.

Engineering Works and Factories Act, by B. S. Dyer. (*Mechanical World, 29th March, 5th, 12th, 19th April,* 1946, *Vol.* 119, *Nos.* 3091, 3092, 3093, 3094, *pp.* 343, 373, 407, 445, 3 *figs.*)

This series deals with: (*a*) the general requirements of the environment having specific bearing on the health of the workers, including adequate internal cleanliness of the factory, space for each individual worker so as to prevent overcrowding, atmospheric conditions, lighting and drainage; (*b*) aspects of safety within the factory, including guards for machinery, carrying out of inspections, adjustments, etc., only by official "machinery attendants," employment of young persons, maintenance of lifting tackle, floors, steps and stairs, precautions to be taken in processes which give rise to inflammable dusts, gases or vapours, provision of safety valves, pressure gauges, water gauges, fusible plugs, and of the statutory inspections and tests for boilers, safety provisions and to means of escape in case of fire; (*c*) provision of welfare facilities within the factory, including supply of drinking water, washing facilities, accommodation of clothing, first aid appliances, prevention of inhalation of dust or fume, protection of eyes, control of humidity, prevention of employment of young persons to handle heavy loads, prevention of employment of female young persons in processes on dangerous material, protection of workers on machines, etc.; and (*d*) notification and investigation of industrial accidents and diseases.

The Identification and Recovery of Scrap Metal. (*Machinery,* 23*rd May,* 1946, *Vol.* 68, *No.* 1754, *p.* 659.)

Scrap is centrifuged to remove oil, dried and magnetically separated. Sweepings from floors can also be treated. Scrap metals can be differentiated by both physical and chemical methods, which are described.

INDEX TO ADVERTISEMENTS

As a war-time measure the advertisement section of this Journal is now published in two editions, A and B. Advertisers' announcements only appear in one edition each month, advertisements in edition A alternating with those in edition B the following month. This Index gives the page number and edition in which the advertisements appear for the current month.

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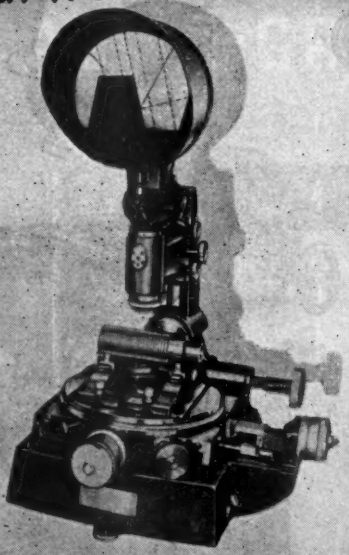

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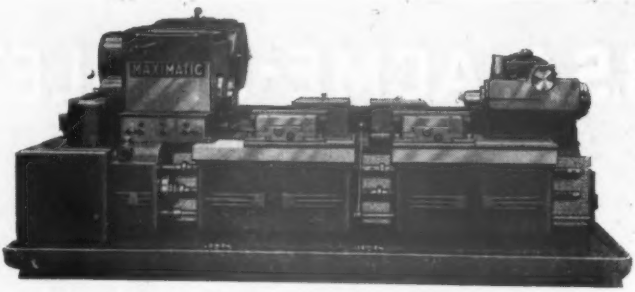

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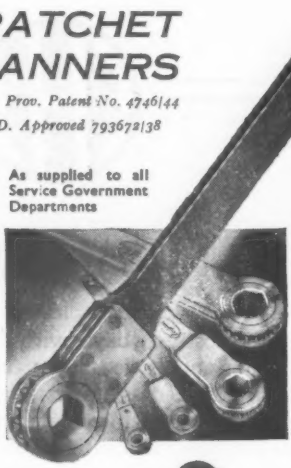

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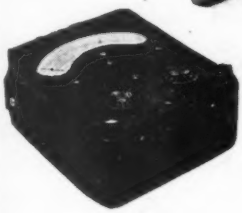

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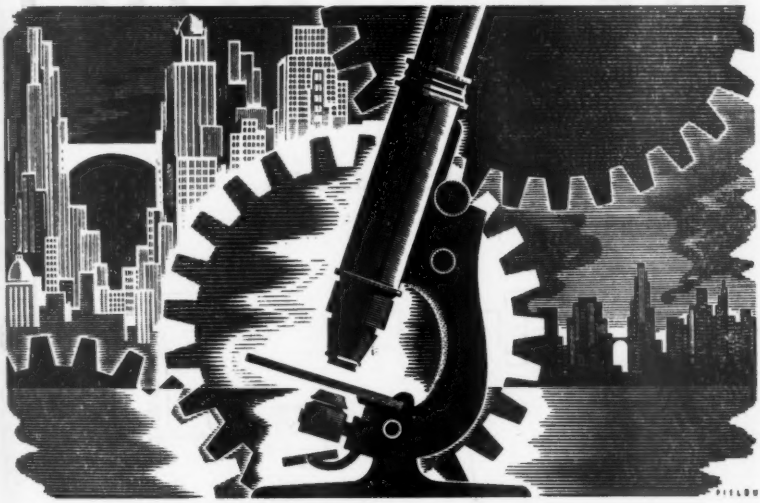

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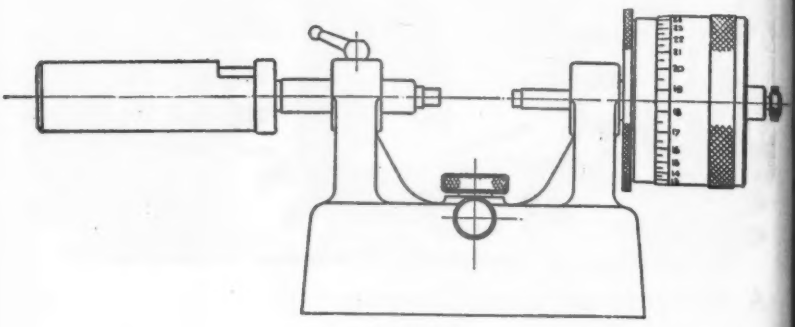

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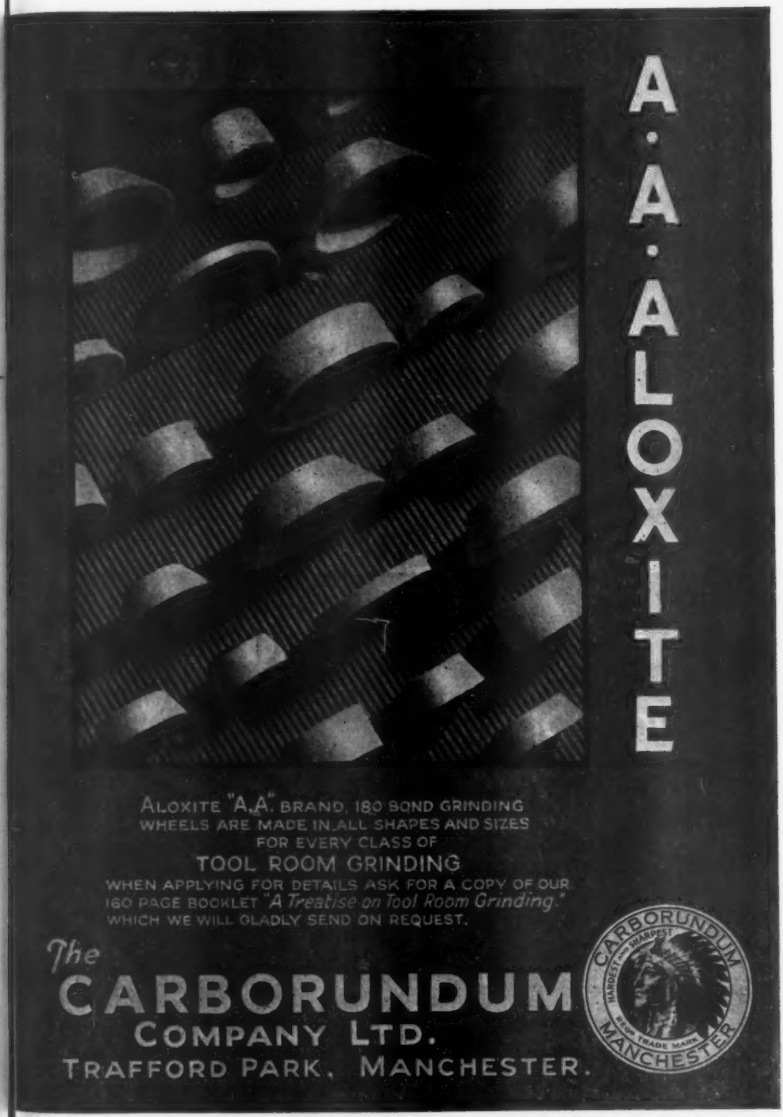
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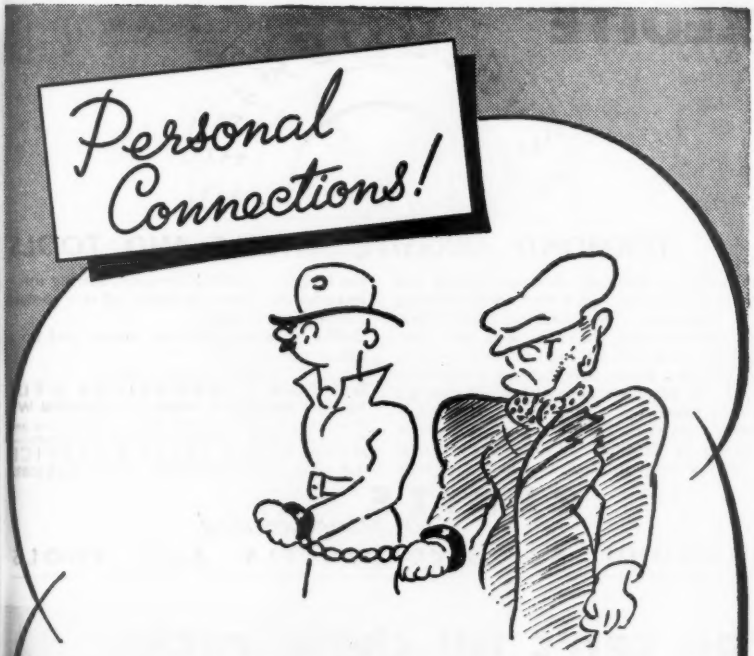

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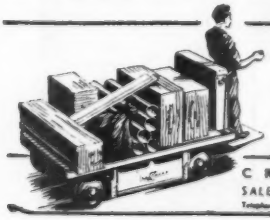

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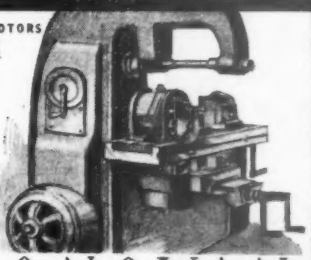

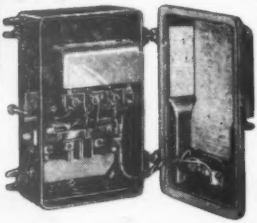

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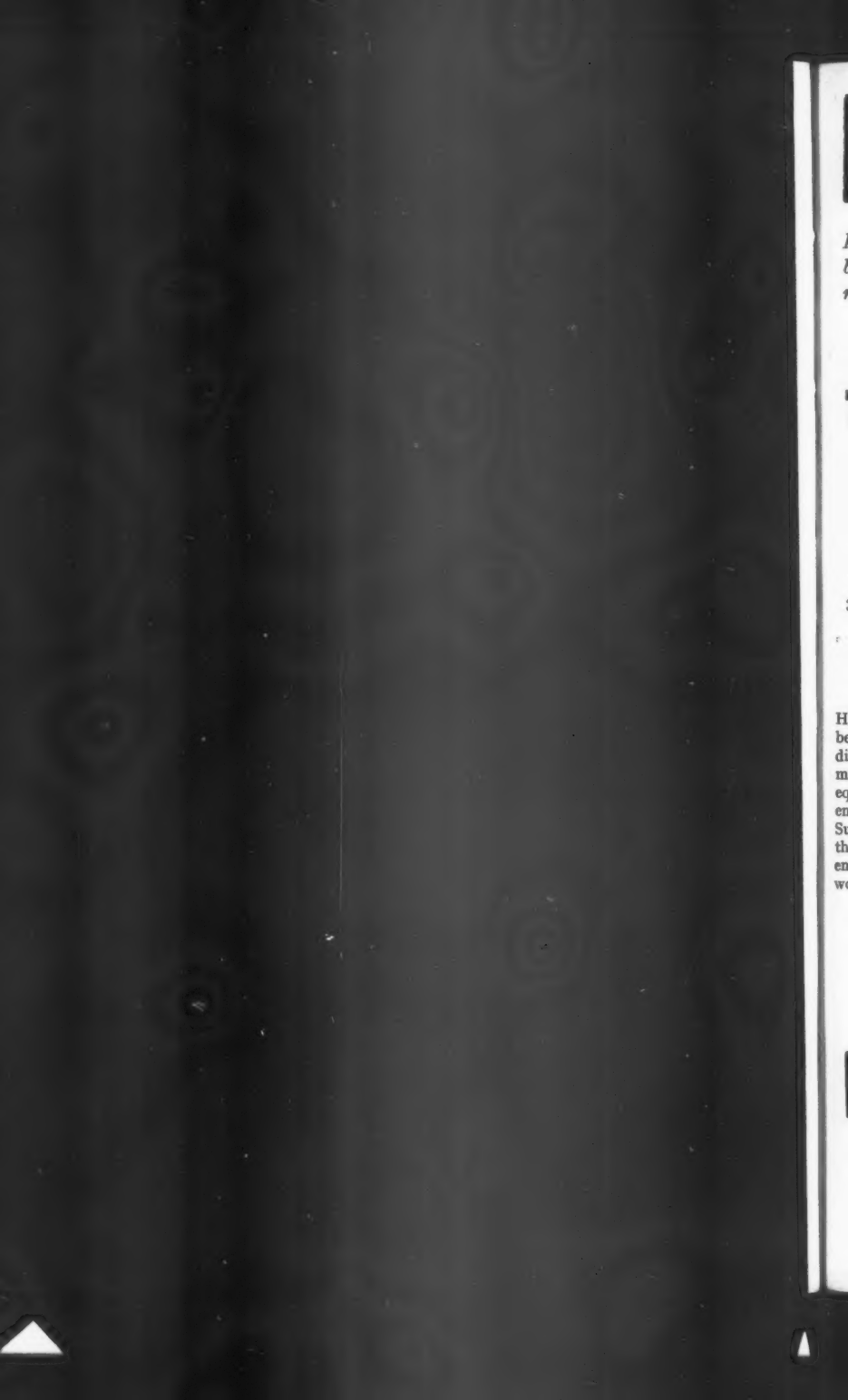

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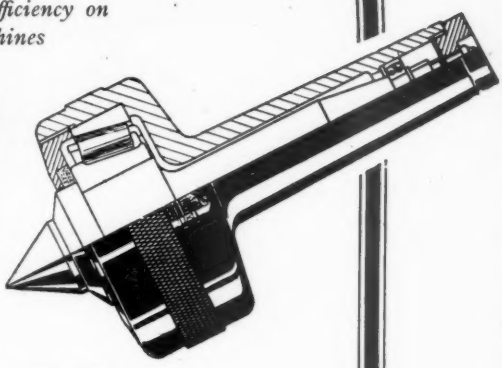

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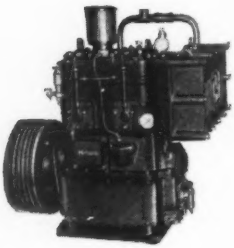

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